UNCLASSIFIED

Defense Technical Information Center Compilation Part Notice

ADP010426

TITLE: JSF F120 Engine Program. Low Cost Operation and Support. An Engine Manufacturer's Perspective

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Design for Low Cost Operation and Support [la Conception en vue d'une exploitation et d'un soutien a cout reduit]

To order the complete compilation report, use: ADA388024

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:

ADP010418 thru ADP010432

UNCLASSIFIED

JSF F120 Engine Program
Low Cost Operation and Support
An Engine Manufacturer's Perspective

K. Murphy
GE Aircraft Engines
One Neumann Way MD G41
Cincinnati, OH 45215-6301
United States

J. Smith
GE Aircraft Engines
One Neumann Way MD G110
Cincinnati, OH 45215-6301
United States

D. Wensits
Allison Advanced Development Co.
P.O. Box 420, speed Code S-22B
Indianapolis, Indiana 46206-0420
United States

Abstract

The JSF F120 engine is being developed specifically to meet the overall affordability objectives of the JSF Program, addressing all elements of cost from development through operation and support. Uniquely different from current systems, the JSF affordability focus is driving fundamental changes in the engine configuration and development, acquisition, and support processes to facilitate meeting these overall affordability goals. Although these changes influence all aspects of the F120 engine design, one of the critical elements to meeting these objectives is improving the supportability characteristics of engine. Improved supportability, implemented through increased reliability, improved safety, reduced maintenance, and flexible support systems, will result in lower overall operation and support costs over the life of the weapon system. These improvements will facilitate the affordable operation of the F120-based propulsion system.

To meet the desired supportability improvements, the F120 engine is being designed as an inherently more robust, lower variation system based on the Team's Six Sigma initiatives to positively impact maintenance and support costs yielding lower total cost of ownership for our customers. The F120 engine design process is focused on configuration simplicity, full 3D simulation, advanced diagnostics, and support system flexibility to achieve the desired cost benefit. The F120 engine's simplicity, with significantly fewer parts than current engine systems, provides the basis for improved reliability and lower cost. Each of these parts is being designed in a full 3D visualization and modeling environment to permit full assessment of maintenance and support needs during the design process. Overall, the engine will utilize an advanced Prognostics and Health Management (PHM) system, combined with the weapon system's Integrated Flight Propulsion Control (IFPC), Vehicle Management System (VMS) and advanced information processing systems, to provide specific data on the health of the engine to facilitate "on-condition" maintenance and support.. Combined with the engine's PHM system is the ability to provide a flexible customer support system to facilitate the operation and support needs of the weapon system's various customers. This flexibility permits easy adaptability to both today's and future systems capitalizing on different partnerships between government and industry. Integrating these focused activities will permit the GE/AADC/RR Team to provide an F120 engine system that optimizes the balance between reliability, maintainability, and support resources to deliver a low cost, maintenance friendly system, ultimately meeting affordability objectives.

Introduction

A key objective of the F120 Program is to provide a fully supportable product that meets the overall affordability objectives of the Joint Strike Fighter Program. To accomplish this, an international team consisting of GE Aircraft Engines, Rolls-Royce plc, Allison Advanced Development Company, and Philips Machinfabrieken has been established to synergistically combine their collective capabilities to make the F120 the most advanced, supportable, and affordable fighter engine in the world. The specific JSF focus on supportability is driving fundamental changes in this team's processes to address all elements of cost from development through operation and support. These process changes provide the basis for the Team's ability to achieve the overall affordability goals of the program.

The F120 engine is being developed through a four-phase, risk-based program fully integrated with the JSF Preferred Weapon System Concept (PWSC) Engineering and Manufacturing Development (EMD) program. Phase I completed the necessary propulsion system conceptual design and weapon system assessment necessary to select the F120 engine as the preferred engine for the JSF program. This phase included a comprehensive technology evaluation process to select the right combination of technologies to meet the JSF program's affordability goals. Phase II, currently in progress, is focused on core engine technology maturation and risk reduction, providing the basis for either of the two Weapon System Contractors (WSCs) PWSC propulsion systems. This phase demonstrates the inherent capability of the F120 core to meet the needs of a Short-Take-Off-Vertical-Land (STOVL) capable propulsion system. Phase II is proceeding on cost and within schedule requirements towards a core engine test in July 2000. The Phase III, or Pre-EMD phase, is structured similar to the Phase II effort, but focused on the turbofan engine system. This phase provides the necessary risk reduction to prepare for a low-risk EMD program in Phase IV. The Phase III contract was recently awarded to the F120 Team, permitting the fan and low pressure system development to proceed. The Phase IV program completes development of the remaining propulsion system components and fully qualifies the F120 engine for production. The Phase IV effort includes the necessary flight test and operational evaluation of the engine. In February 1998, the US DOD certified that the F120 program is fully funded and detailed planning of the complete program is in process.

The JSF F120 engine is a dual-spool, fixed cycle, and multi-mode turbofan propulsion system, designed to specifically meet the JSF multi-service, multi-national weapon system

Paper presented at the RTO AVT Specialists' Meeting on "Design for Low Cost Operation and Support", held in Ottawa, Canada, 21-22 October 1999, and published in RTO MP-37.

requirements. The engine is derived from the successful YF120-GE-100 engine developed in the Advanced Tactical Fighter Engine (ATFE) Program. This engine, with its inherent core capability, provides an excellent basis for meeting the JSF propulsion system requirements for either of the two PWSCs under consideration. For each concept, a tailored, derivative engine configuration has been defined to meet unique needs of each WSC. In either case, the F120 operates in a separated flow mode for STOVL, with core and fan airflow streams separately used for propulsive lift components. For Conventional Take-Off and Landing (CTOL) and Carrier Version (CV) variants, the F120's mode of operation is as a conventional mixed-flow, augmented turbofan engine system.

Although all aspects of the life cycle are important to cost operation and support costs, at approximately 40% of today's life cycle cost, are key contributors and must be dealt with differently than in traditional development processes if the affordability goals of JSF are to be met. For the F120, fundamental changes to these processes are being made to achieve the desired results.

Process Improvement

To achieve the objectives of JSF, a new approach to development, acquisition, and operation and support is necessary. Process improvements are being implemented across all functional areas for all phases of the F120 program. Of primary importance, operation and support must be included as a fundamental requirement at the very beginning of the development process and treated as an independent design variable, just like thrust, specific fuel consumption, and/or cost. The F120 Team program has been structured to provide the required focus on operation and support from the beginning of the development process.

With the launch of the Phase II core demonstration effort, the F120 Team has focused its attention in the following key activities to ensure life cycle affordability for the JSF engine, implementing necessary process changes to provide a fully integrated result:

- Formulating specific, allocated requirements derived from the WSC Tier III specifications provided to each component design team to drive suppportability assessments from the beginning;

- Applying GE Aircraft Engines New Product Introduction/Engine Development Cycle (NPI/EDC) and Six Sigma initiatives to the F120 program, including specific application of Design For Six Sigma (DFSS) and Design For Reliability (DFR) processes to provide the desired quality and reliability capability;

- Establishing a comprehensive Reliability, Maintainability and System Safety (RM&S) Program where RM&S engineers are active participants in the individual component development Integrated Product Teams (IPTs);

- Including a comprehensive Prognostics and Health Management (PHM) capability into the engine control system to meet the underlying supportability objectives of autonomic logistics and enhanced failure detection capabilities; and,

- Initiating advanced logistics support planning early in the program to assess innovative support concepts and ways to minimize the logistics costs while achieving maximum sortie generation.

Implementing these activities as an integral part of the overall development program will permit the F120 Team to successfully meet JSF's operation and support cost objectives.

Design Process Improvement

The design of the F120 engine is being executed based on the use of GEAE's NPI/EDC and similar processes at each of the other Team member organizations to provide a higher quality, more reliable, lower cost product that meets the full affordability objective of the JSF Program. The design of the F120 is being conducted through the use of Design for Six Sigma and Design for Reliability processes being implemented across the F120 Team. These process improvements provide a statistical method of evaluating process capability against requirements, provide component and system level product scorecards for tracking, and define a means of trading capability to meet the desired requirements.

The NPI/EDC process addresses the entire product life cycle from idea inception to product retirement. It defines the series of milestones, or "tollgates", that must be achieved at specific points in the program for it to successfully proceed to completion. The tollgates describe the type of business, project, and technical data necessary to make sure sufficient information is available for proper decisions to be made. Each of these tollgates has a specific set of criteria that ensure all aspects of the program are properly considered. Through the use of this process, the right data is generated in a timely manner, avoiding unnecessary effort.

Within the JSF F120 program, there are a significant number of new analytic tools and processes being used that are providing the team the ability to meet the program's affordability objectives. Three examples can be used to highlight the types of changes being made to improve operation and support costs: target costing, smart, simple design, and master model simulation. The first of these processes, target costing, is one of several cost-focused process improvements being made across the Team. It provides a cost target for every part in the engine based on the requirement provided by the WSC for their PWSC configuration.

This process uses GEAE's advanced COMPEAT\$^{TM} cost model, which permits a feature-based cost assessment of each component's design. The second type of process, Smart, Simple Design (SSD), is one of several techniques focused on reducing the number and complexity of the engine components, along with reducing manufacturing, maintenance, and repair processes and costs. These techniques provide focus on simplifying and/or combining functions to produce more affordable components, along with the use of standard parts. The third type of process, master modeling, is a package of software that provides a single database for use by the Team. The F120 Team is utilizing master models of all component hardware in a common data base to permit all disciplines, from design to manufacturing, to utilize the same analytic representation for all design, including supportability and manufacturing analyses. These master models are all full 3D solid simulations of the hardware, permitting a full assessment of the part prior to manufacture. These tools, along with a host of others, are providing the Team with the basis of producing a supportable, affordable design.

Supportability Process Improvements

Traditionally, RM&S has not been treated as an independent design variable, but only as a measure of the overall system capability after the design has evolved sufficiently in the development process. The F120 Team has undertaken three key activities to consider RM&S as an independent variable and overcome this historic limitation:

- Evaluating legacy system capability to assess what reasonable RM&S goals should be set for the F120 engine system;
- Interpreting the specific WSC requirements, flowing them down to the individual engine component Integrated Product Teams (IPTs); and,
- Establishing a system evaluation process to trade capability with each independent variable, including cost, between individual components within the engine.

The Team is integrating the results of these three steps, balancing the needs of all elements of the propulsion system while providing a comprehensive process for achieving the desired goals. The F120 Team is working with JPO, both WSCs, and P&W to thoroughly understand all the weapon system and propulsion requirements.

Improved reliability is the corner stone to reducing maintenance cost and improving support over the life of a weapon system. Today's engines typically require some sort of corrective maintenance action approximately every 50 flight-hours to repair inherent, induced, and/or no-defect failures. Of these three types, inherent failures occur as a direct result of deficiencies in the inherent design characteristics of the system and this is where we, as an engine manufacturer, have the greatest ability to help reduce operation and support costs. It is in this area that the F120 Team is focusing its DFSS and DFR quality initiatives to design an inherently more reliable system. Using specific customer requirements, legacy system lessons-learned and aggressive goals, detailed Failure Modes, Effects and Criticality Analyses (FMECA) are being performed to ensure inherent reliability is designed into the F120 system. Overall, inherent failures will be effectively minimized through implementation of the F120 reliability program.

In addition to the focus on inherent reliability, the F120 Team is also aggressively pursuing design features that will minimize the possibility of induced failures later in service. Current experience suggests that 30% of air and ground aborts are directly attributable to maintenance induced failures. Induced failures typically occur as a result of performing maintenance to correct one problem and inadvertently introducing another fault in the process. This can occur directly while performing an appropriate maintenance action, but also frequently occurs during part cannibalization from other engines due to inadequate spare part availability. Control of induced failures has been traditionally managed by the user, through careful maintenance practices and attention to spare parts availability. Beyond these traditional approaches, however, the F120 Team is aggressively pursuing support concepts that will minimize parts shortage problems and design features that will minimize the possibility of mishandling and/or miss-assembly. These efforts will ultimately minimize the occurrence of induced failures. Maintainability and human factors engineers are part of the IPTs, working with the component designers to implement a comprehensive list of maintainability and human engineering features created specifically for the F120 engine.

To help address the induced failure issue, an advanced 3-dimensional solid modeling capability is being implemented to assess maintainability characteristics before engine hardware designs are completed. Instead of physical mock-ups, the F120 Team is using a combination of commercial 3D CAD and GE developed software to provide a full, electronic simulation of the engine, built from the individual part level. This simulation, or Digital Pre-Assembly (DPA), in concert with advanced visualization tools, is being used to simulate component and engine assembly, providing an early assessment of fits, clearances, and assembly procedures. These tools help identify and assess design changes that are necessary to meet supportability considerations early in the design process when they can be implemented most cost effectively. This early attention to detail will minimize overall development costs through the reduction of downstream re-design and will minimize exposure to maintenance induced failures in the future. Upon completion of the design process, this full engine simulation will become the basis for user maintenance and support training.

For the F120, the no-defect failure category will be minimized through implementation of a comprehensive,

integrated Prognostics and Health Management (PHM) system. No-defect failures can occur because of inadequate troubleshooting practices and procedures, which lead to unnecessary removal of perfectly good parts. The inability to isolate faults to a single component results in multiple parts replacement and ultimately contributes to the cost of ownership. Through the use of the F120 PHM system, fully integrated with the engine and vehicle control systems, the operation of the engine will be monitored on a real-time basis, comparing its performance against a theoretical engine simulation. This comparison will be used to assess the health of the engine, providing data for use in life management and maintenance planning. The PHM system, using a suite of specialized sensors, will be able to provide specific data on component characteristics and permit significant improvements in fault isolation. Overall, the PHM system will be able to guide the user on what they will need to do to maintain the engine system in the field. This system will permit the focus to change from periodic inspections to "on-condition" maintenance, avoiding the cost for inspections that may not be necessary.

Concurrent with the efforts of F120 reliability and maintainability engineers, system safety engineers are active participants in the IPTs to ensure the maximum safety of personnel and equipment throughout design, test, operation and support phases of the program. A comprehensive safety program is in place and in-depth safety analyses are being performed to identify all potential safety hazards. The payback is real, but intangible, since there isn't a meaningful way of quantifying the benefit of aircraft losses that do not occur. Clearly, significant savings result for every catastrophic failure that does not occur.

Prognostics and Health Management

For the F120 engine system, the PHM system is an integral part of the logistics support system, with two primary objectives. First, it will facilitate implementation of the government's autonomic logistics concept, permitting the PWSC to achieve its sortie generation rate goals. Within the autonomic logistics system, the PHM system will provide the capability to determine operational status of the propulsion system within a returning aircraft prior to its arrival, without manual intervention. Second, it will enhance engine failure detection capabilities and life usage management. The PHM system will not only detect a degraded condition before it becomes an actual failure (prognostics), but will minimize the occurrence of no-defect failures through enhanced fault isolation capabilities. This enhanced fault isolation capability, along with life usage monitoring, will further benefit the management of spare parts supplies, thereby reducing the occurrence of maintenance and reducing operational support cost.

Logistics Support

In addition to delivering a safer, more reliable and maintainable engine, innovative approaches to customer support needs are also being investigated by the F120 Team to meet the specific needs of each of WSC. The F120 is being designed to be sufficiently flexible to operate within either a traditional support infrastructure or an original equipment manufacturer (OEM) "power-by-the-hour" concept, or some variation in between. As currently anticipated, traditional support concepts will necessarily be modified to address the rapid deployment environment of our future military. Partnerships between the F120 Team and government agencies will be developed to address the ever-increasing cost of support and asset management. Emphasis will be placed on reducing spare assets and utilizing "just-in-time" delivery of critical parts.

Engine Interchangeability

One of the key elements of improving the supportability of the weapon system is the use of two, fully interchangeable engines. Commonly referred to as "Plug and Play," the PWSC will be able to utilize either F119 or F120 engine alternative, in any variant, without changing or modifying the airplane. In today's systems, such as the F16, alternative engines are available, but they are not interchangeable. The JSF vision is to provide full engine interchangeability to meet supportability, fleet readiness, and cost objectives. This requirement has necessitated GE and P&W to cooperatively work together to provide this capability. For each WSCs PWSC propulsion system, GE and P&W are working to define the physical and functional interfaces that will enable either the F119 or F120 engine systems to work equivalently in the weapon system.

Summary

The JSF F120 Program is an international endeavor that is synergistically combining the capabilities of GE Aircraft Engines, Rolls-Royce plc, Allison Advanced Development Company, and Philips to produce the most supportable, affordable engine for JSF. The F120 engine effectively addresses reliability, maintainability, safety, and supportability needs integral with the design process to ensure affordability objectives can be met. The F120 design defined for each WSC balances reliability, maintainability, safety, and support objectives to deliver an engine that fulfills the need for low cost operation and support.